SPARC_LAB activity report

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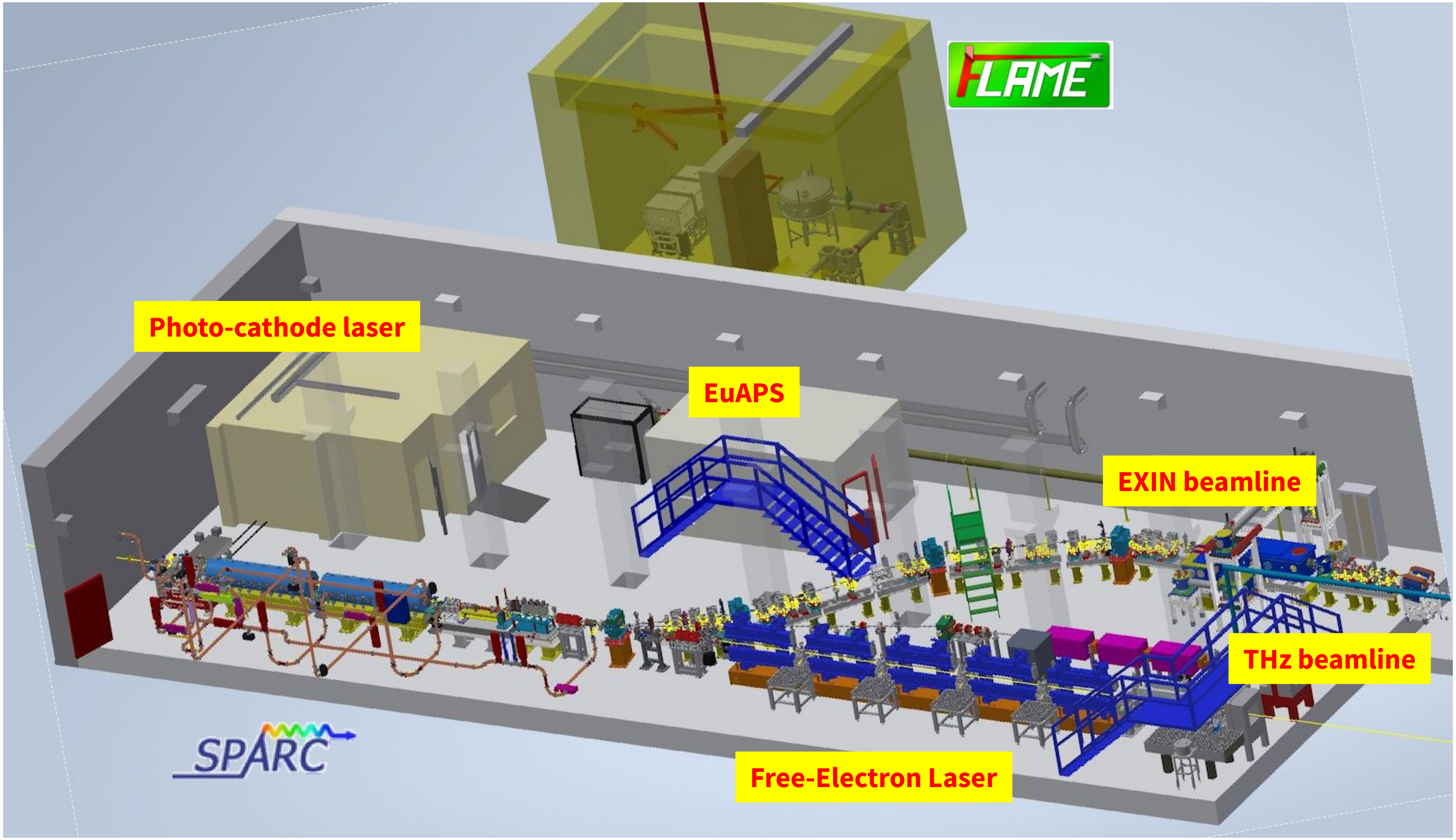
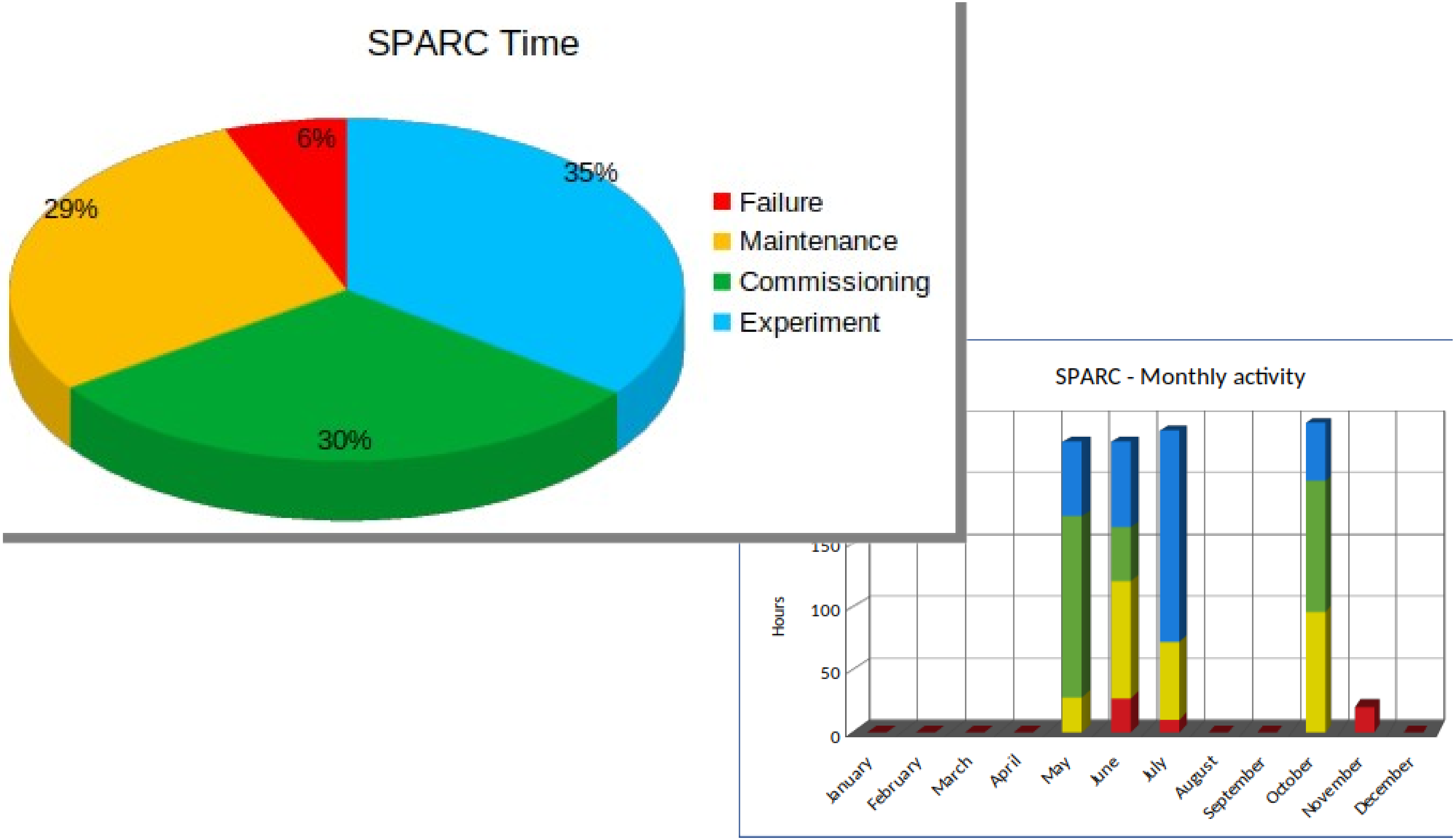
On behalf of the SPARC_LAB collaboration

SPARC_LAB facility



Ferrario, M., et al. "SPARC_LAB present and future." NIMB 309 (2013): 183-188.


SPARC Time
6%
35%
29%
30%
Failure
Maintenance
Commissioning
Experiment
SPARC - Monthly activity
Hours
150
100
50
0
January
February
March
April
May
June
July
August
September
October
November
December

Comments from previous review

- *“SPARC LAB demonstrated that acceleration gradient of 1.2 GeV/m was possible by using a larger drive bunch charge than before. Operation at high gradient is the key feature of plasma-based accelerators. It was also shown that fields or perturbations persist for a longer time after passage of the drive bunch in an H2 plasma than in a N2 plasma. Operation with a N2 plasma would thus allow for operation at a higher repetition rate than with a H2 plasma, though this is not a limitation for the maximum expected repetition rate of 400 Hz. However, pumping speed is much higher with N2 than with H2.* ***Operation with N2 plasma may thus be chosen, mostly for vacuum performance reasons.****”*
    - *Following the committee comments we are now using N2 gas both in short and long capillary prototypes. The vacuum level is under control even when working at 10 Hz with 3-5 ms valve aperture times.*

All-in-one capillary results

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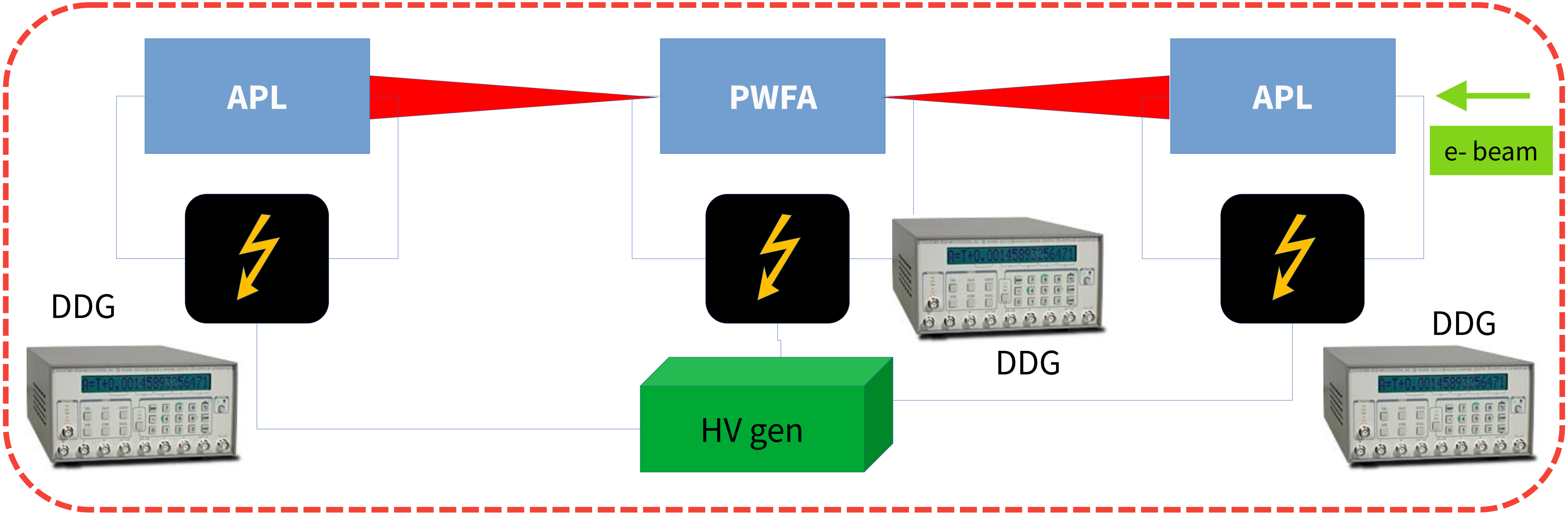
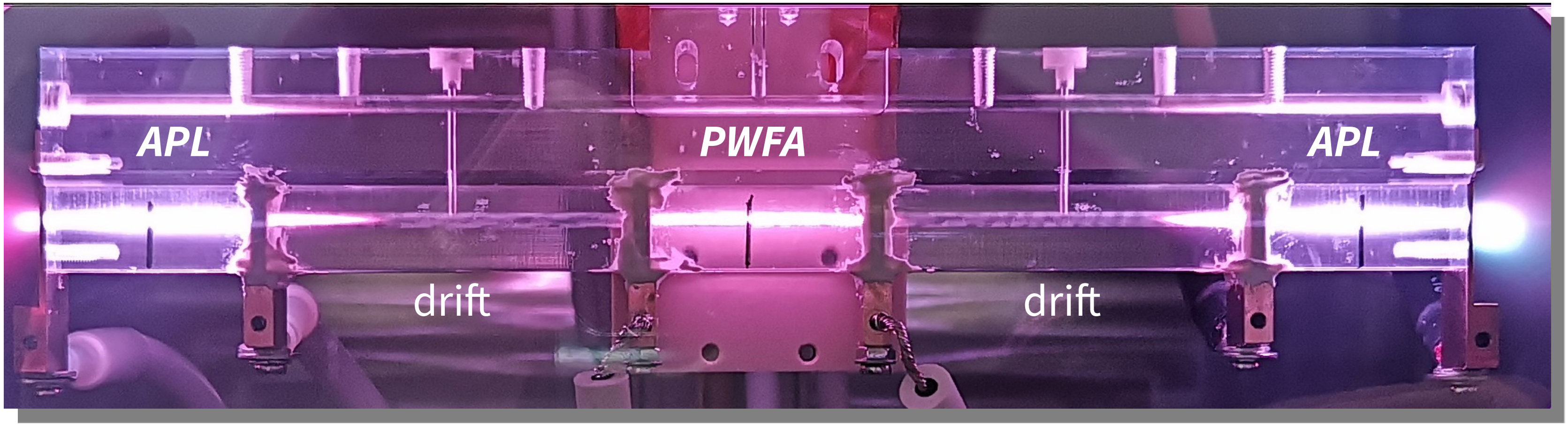
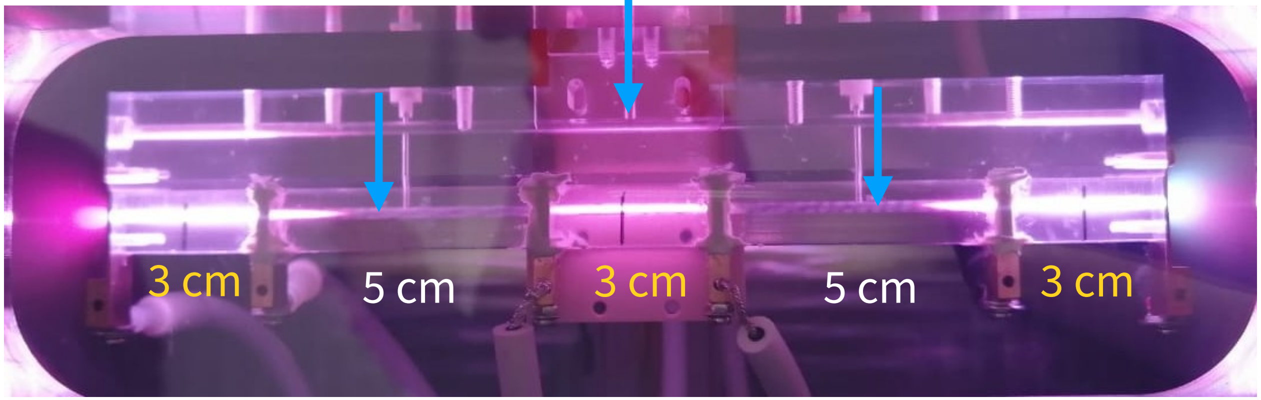
Basic idea of the "all-in-one" capillary



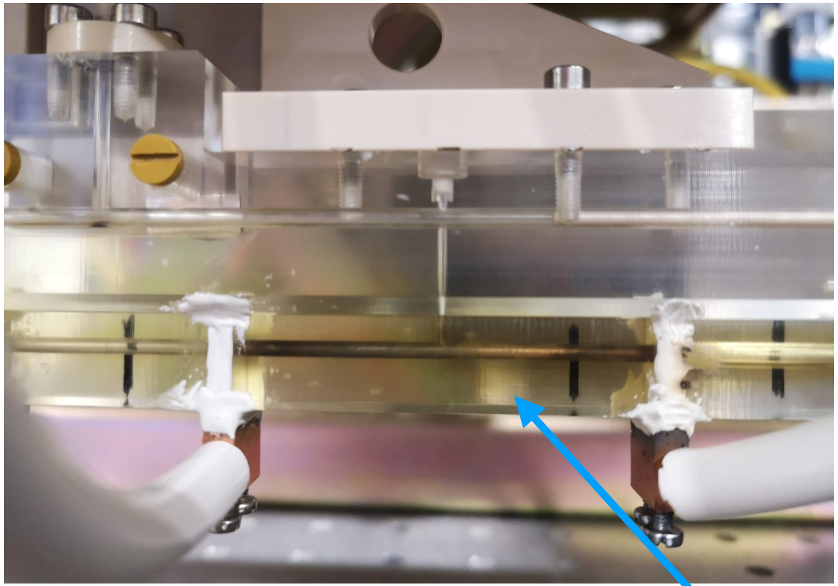


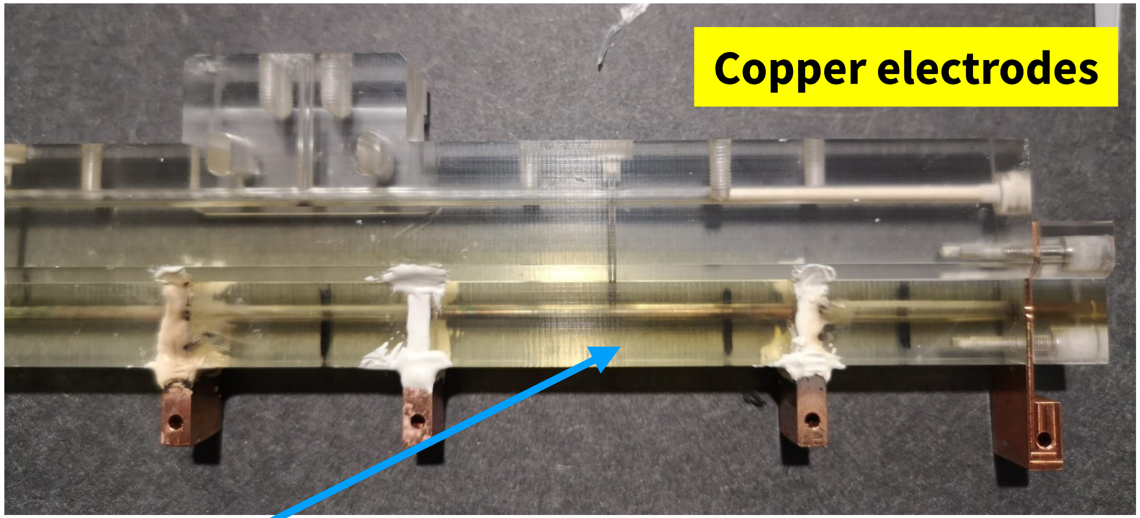
First offline tests (2 inlets prototype)

H_2 or N_2



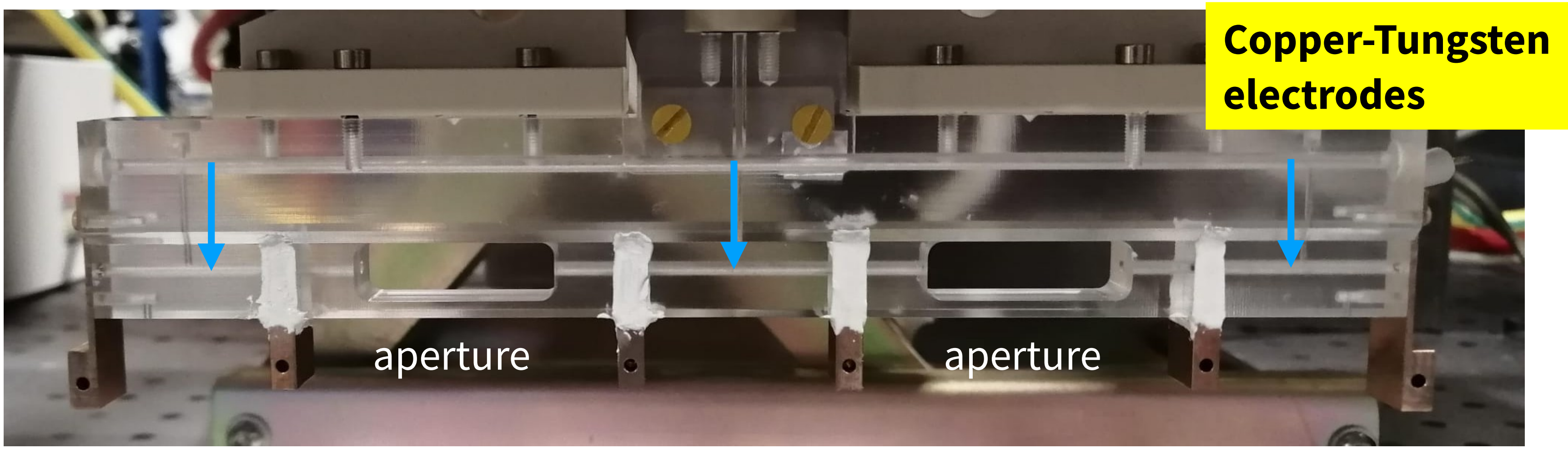
Offline tests
@ PLASMA_LAB

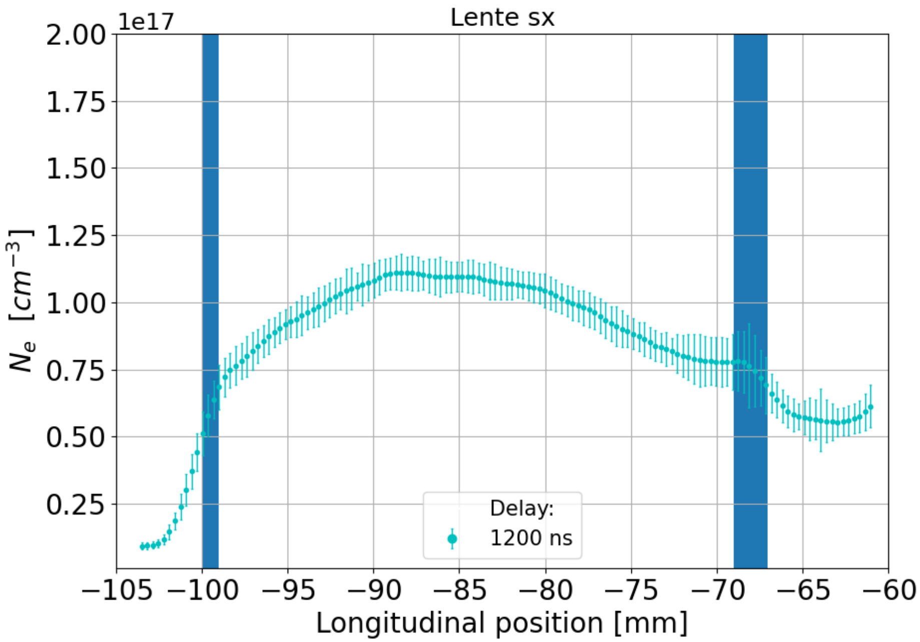


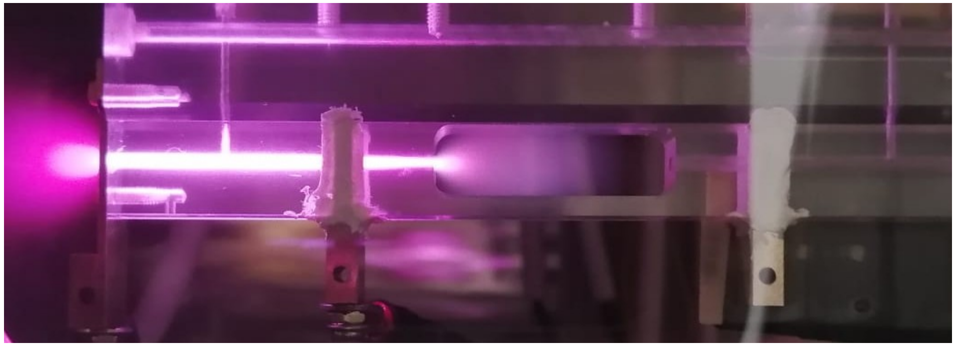


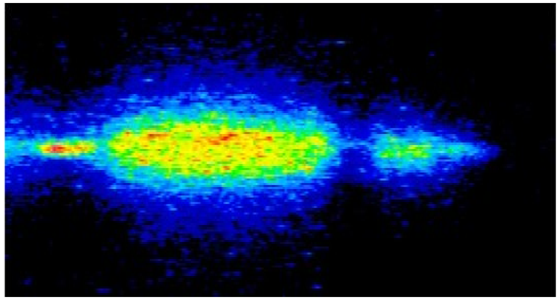
Spattered copper

New prototype (3 inlets)



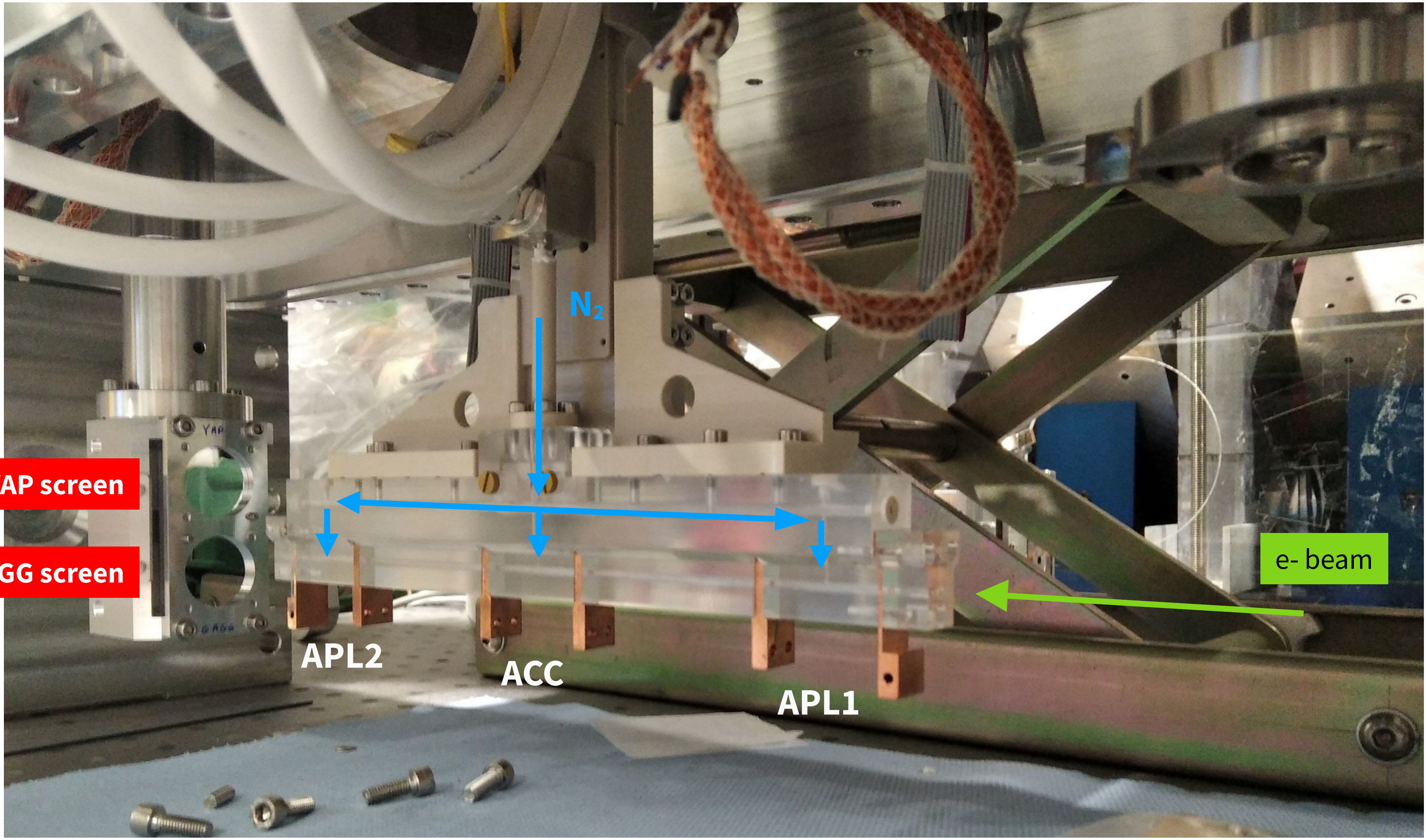




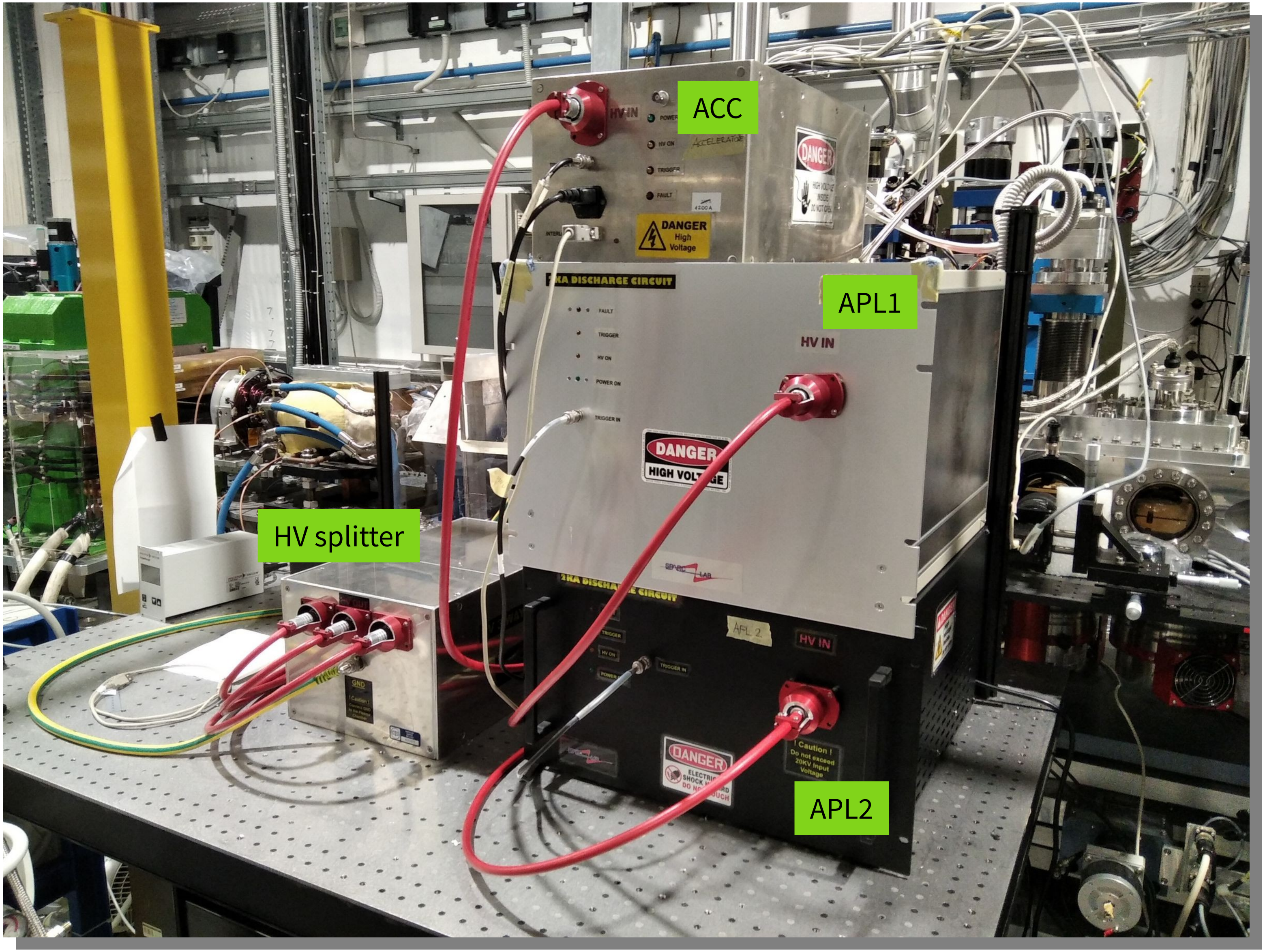


Stark-broadening Measurement with Hydrogen

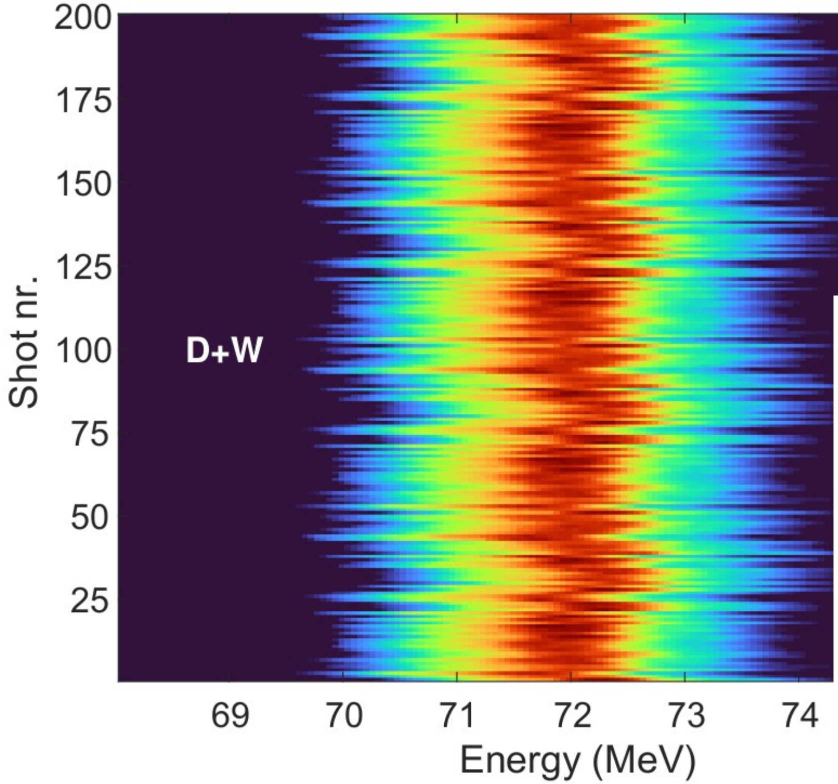
Installation in the vacuum chamber



HV setup

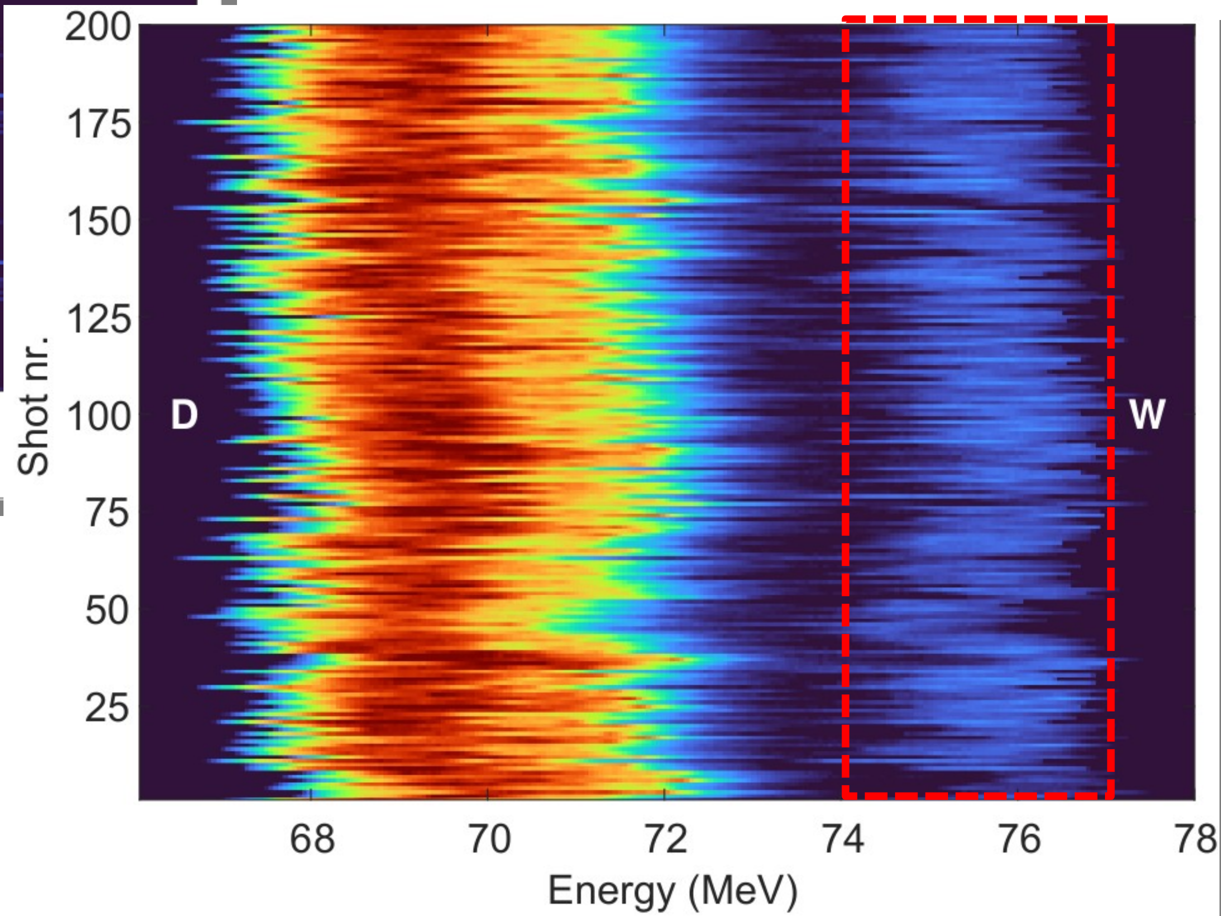

ACC
APL1
HV splitter
APL2
DANGER
High Voltage
DANGER
HIGH VOLTAGE
HV IN
HV IN
HV IN

First accelerated witness



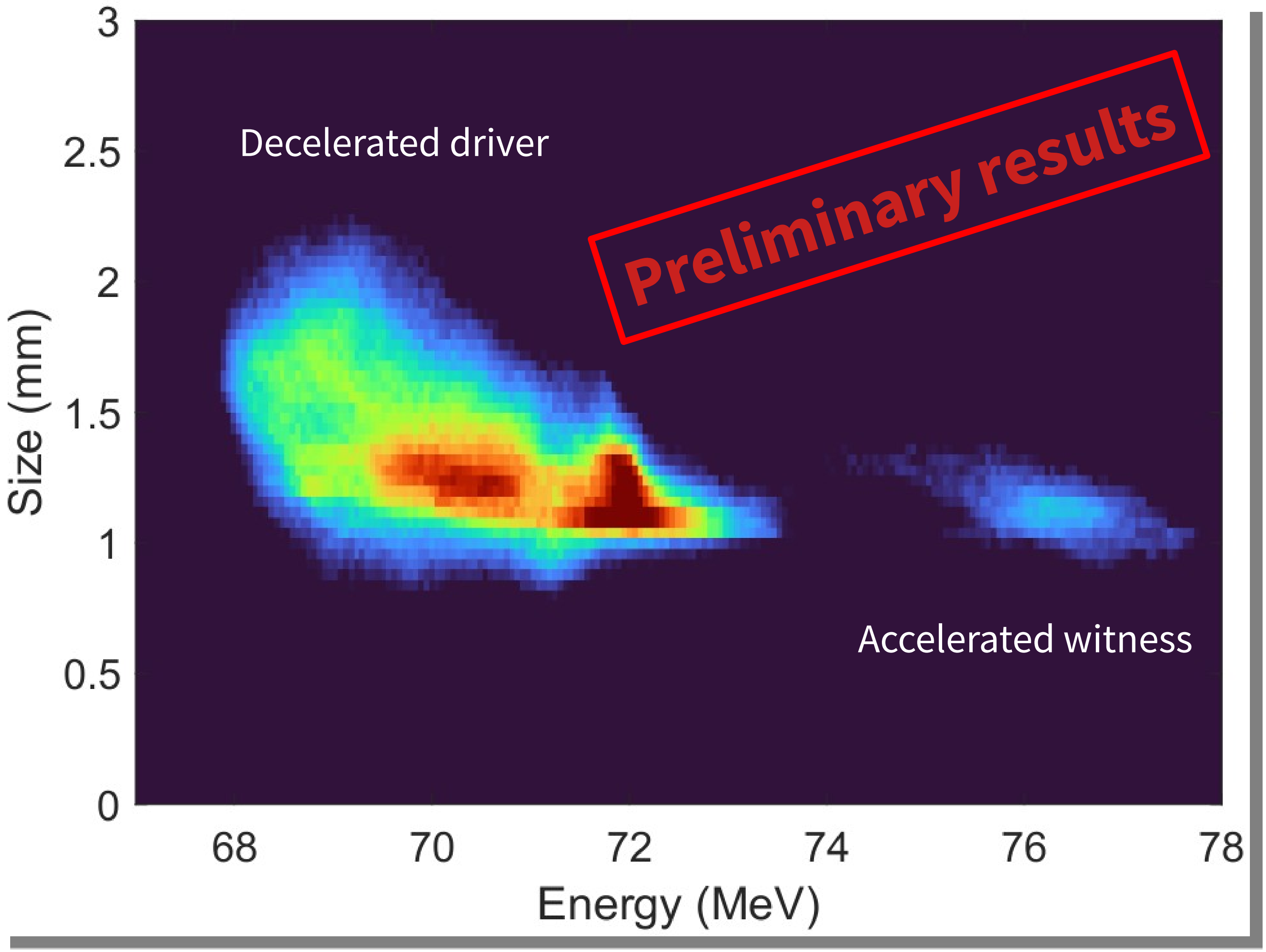
Lenses ON, Accelerator **OFF**

Lenses ON, Accelerator **ON**



Preliminary results

Single-shot spectrum



Active-plasma bending results

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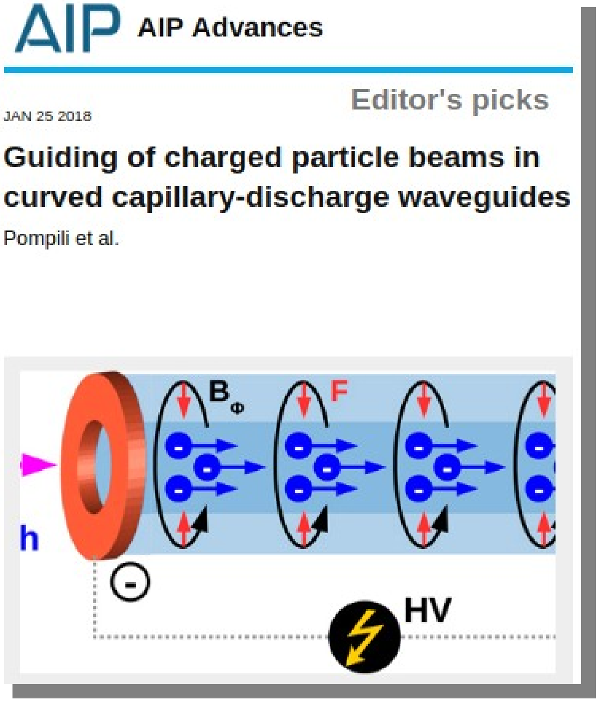
Bending of particle beams with plasma

Active Plasma Bending (APB) is an extension of the Active-Plasma Lens (APL) mechanism

- *The Lorentz force due to the current-induced magnetic field pushes the particles toward the capillary axis*
- *The same applies in a curved capillary: particles stay close to the bent path*
- *Plasma can sustain large currents (> 70 kA have been proved). As an example, **25 kA** currents produce **~6 T** magnetic fields*

Idea is to provide an alternative to classic bending magnets

- *Compactness. Large deflection angles, no need of cryogenic systems*
- *Tunability. The bending is tuned by adjusting the discharge-current*
- *Cheap solution (capillary+discharge pulser)*
- ***Tunable dispersion (dispersion-free also possible) by changing the discharge current***

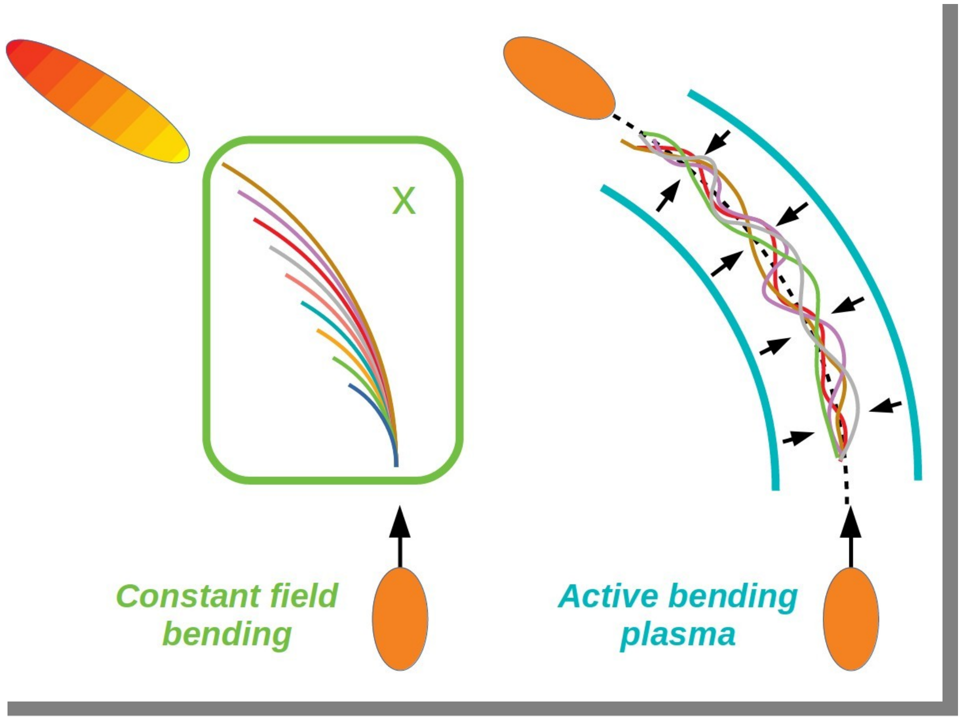


Pompili, R., et al. "Guiding of charged particle beams in curved capillary-discharge waveguides." AIP Advances 8.1 (2018): 015326.

Working principle

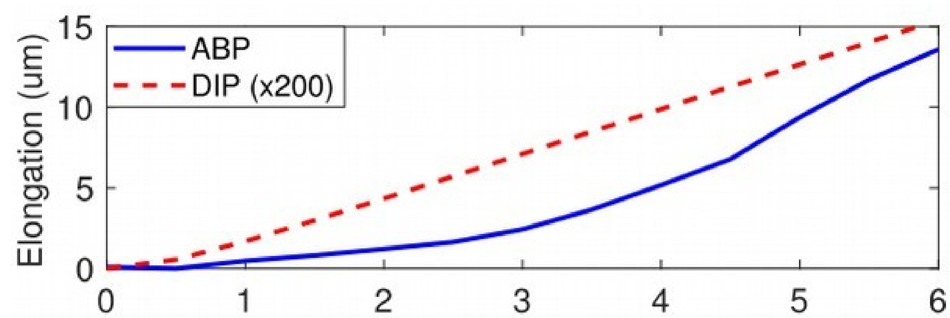
Particle motion in the APB is different with respect to a classic bending magnet

- *Its magnetic field is radially increasing (not constant like in a planar bend)*
- *Large energy particles → large offset with respect to the capillary axis → stronger deflection*

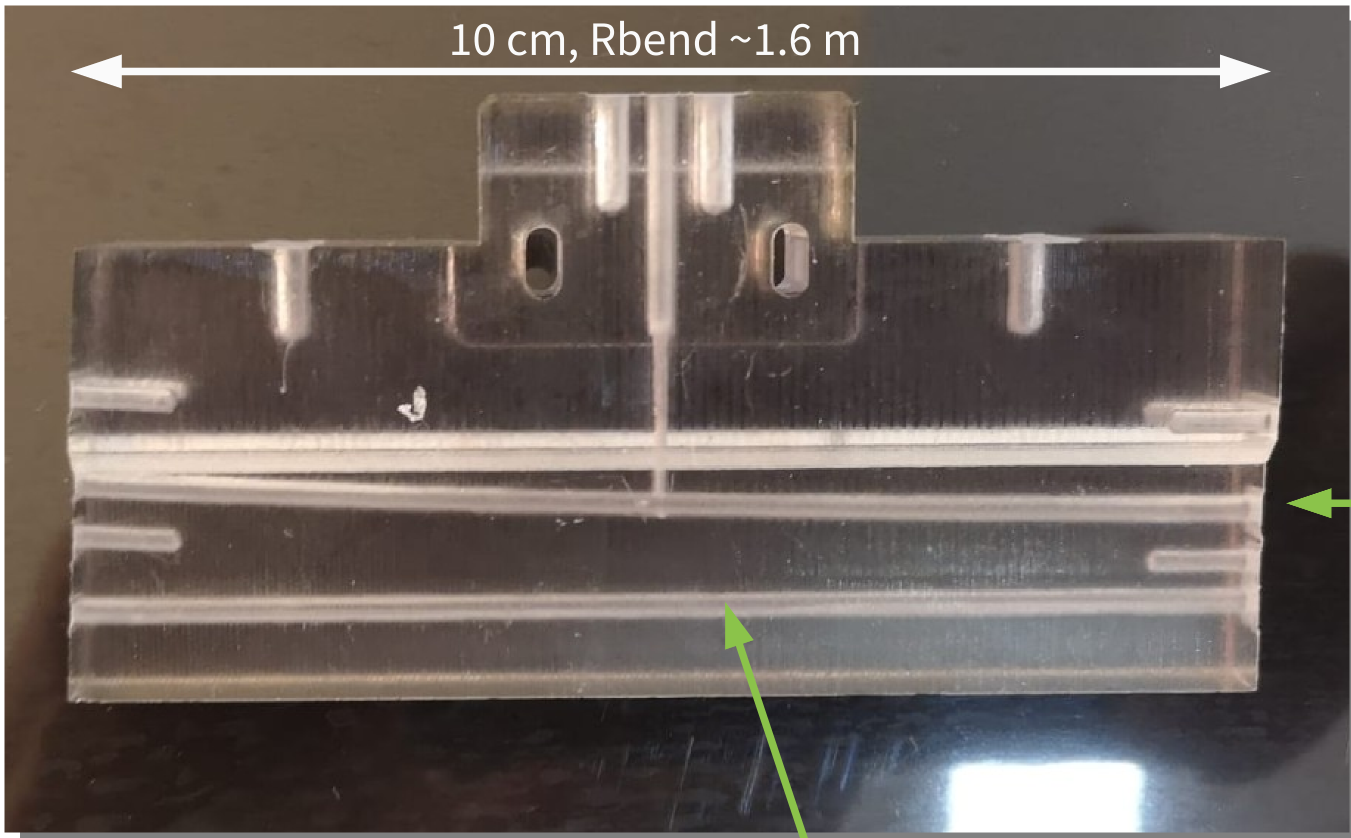


Bunch elongation/dispersion can be made negligible even with large energy spreads

- *The ABP does not require any manipulation on the beam LPS as in the case of standard bending magnets!*
  - *No dispersion-matching optics (quads, sextupoles)!*
- *Simple and affordable solution in view of compact machines.*



SPARC prototype (3D printed)

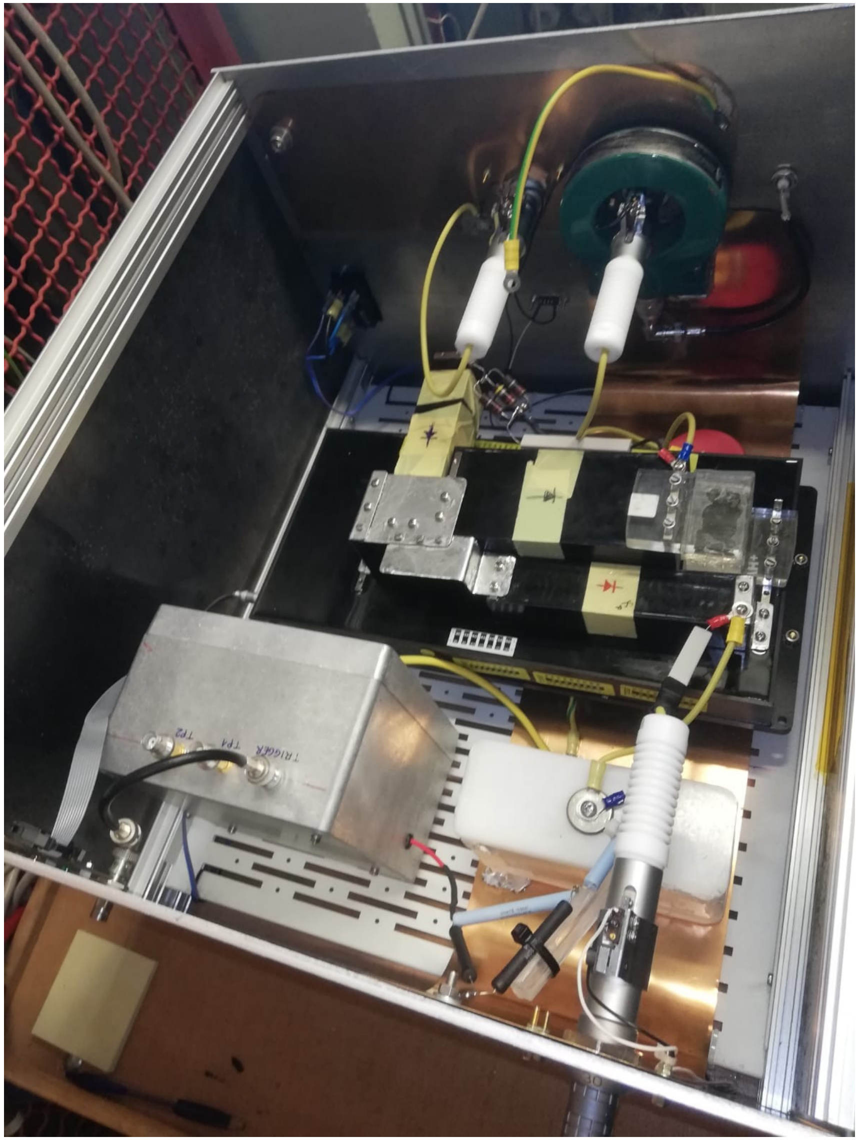


Vertical bending
3 mm offset
2mm hole

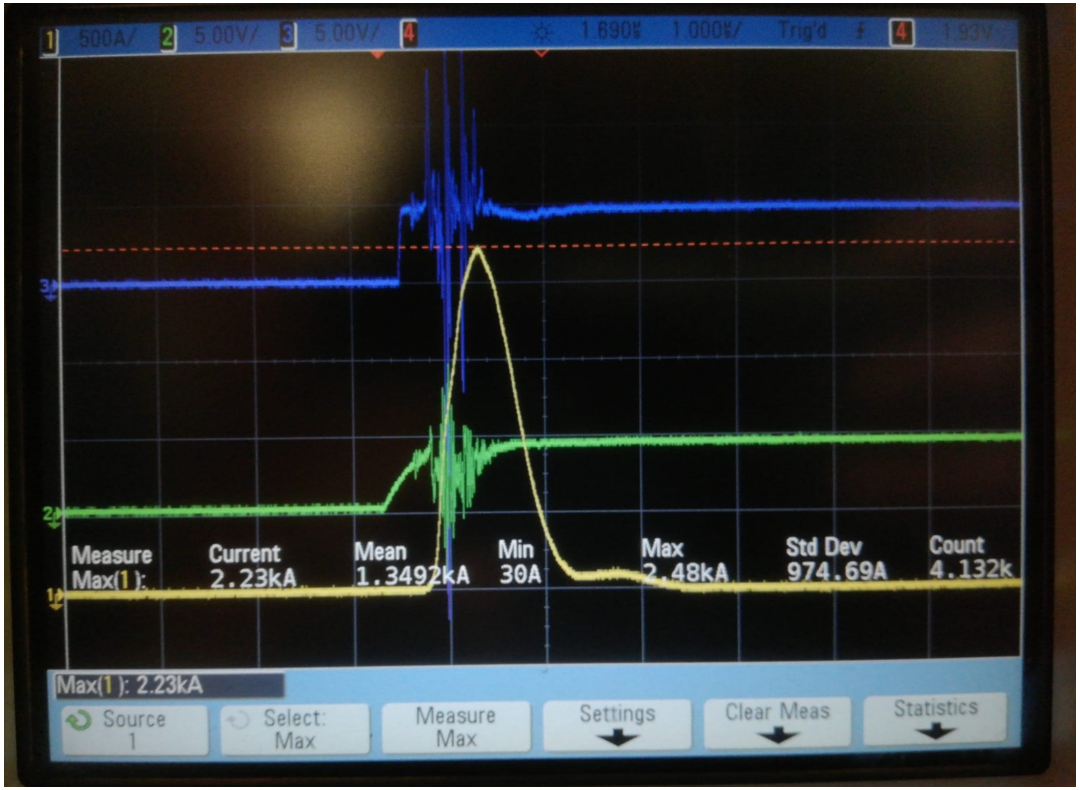
beam

Hole for laser alignment

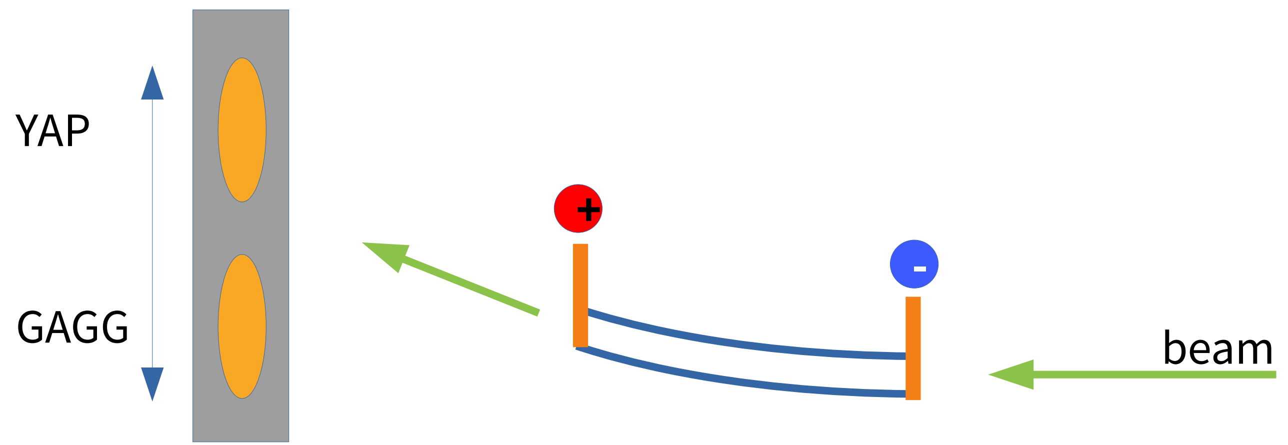
Discharge pulser



HV pulser (thanks to D. Pellegrini, T. De Nardis)



Latest results @ 2.23 kA



We have used a 50 pC test beam on-crest (~1 ps)

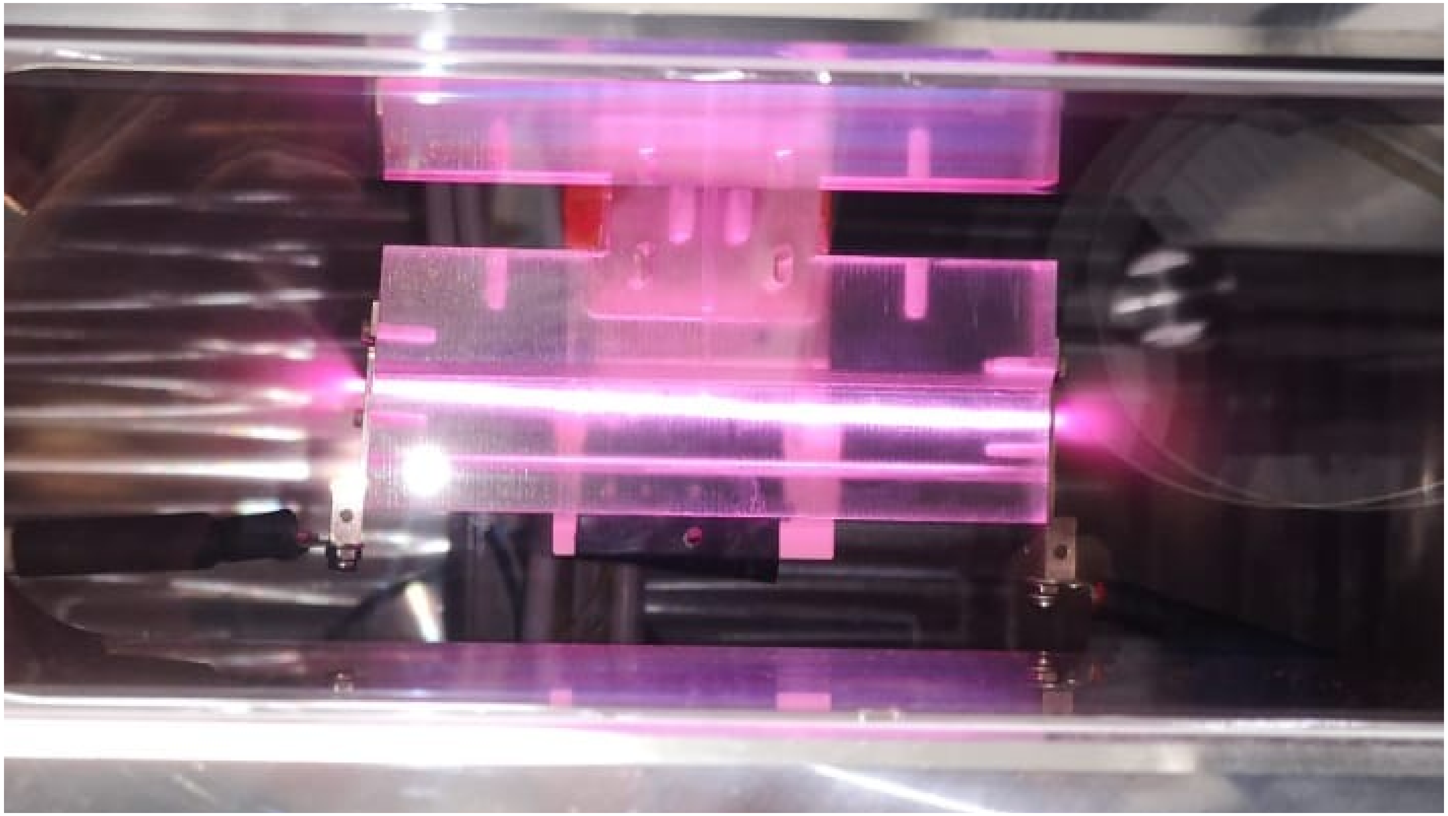
The energy of the beam is set to 60 MeV

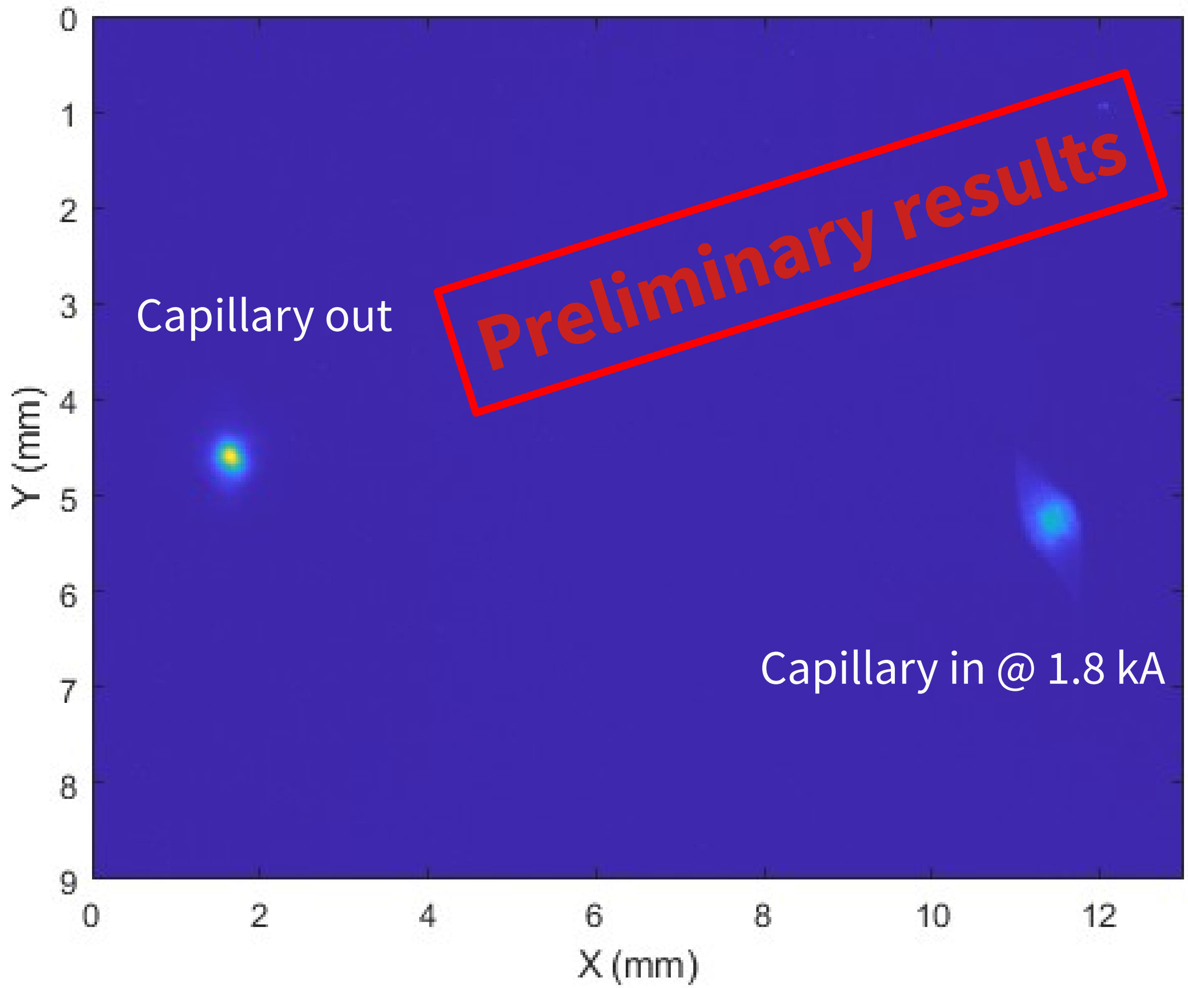
1.6 m bending radius, ~4° deflection angle in 10 cm capillary

The beam is imaged on the YAG/GAGG screen located ~10 cm downstream the capillary exit

Put an energy-chirp on the beam to evaluate the beam dispersion @ screen

Offline tests @ PLASMA_LAB





Vertical axis

FLAME

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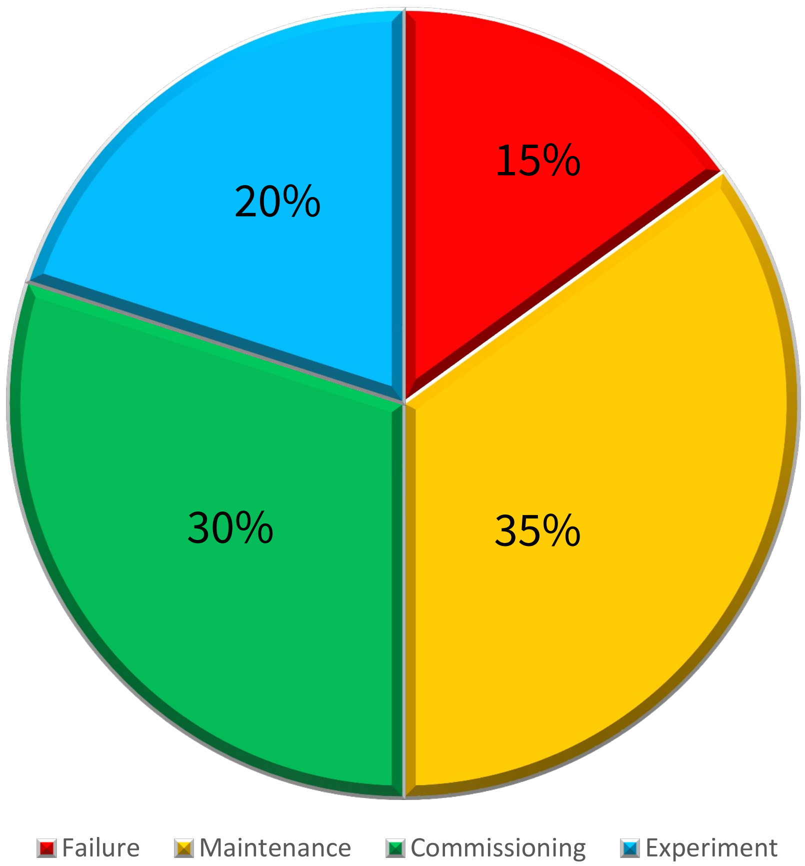
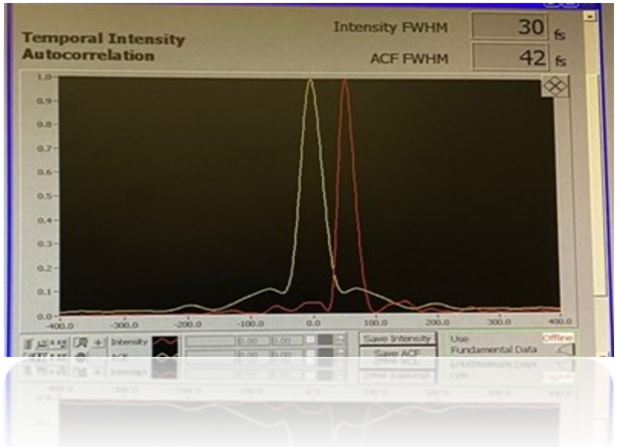
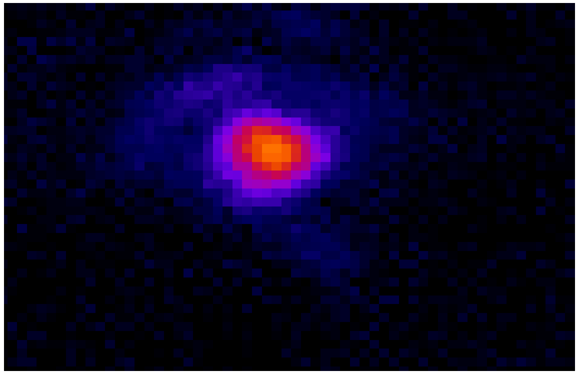
FLAME uptime in 2023



Laser parameters

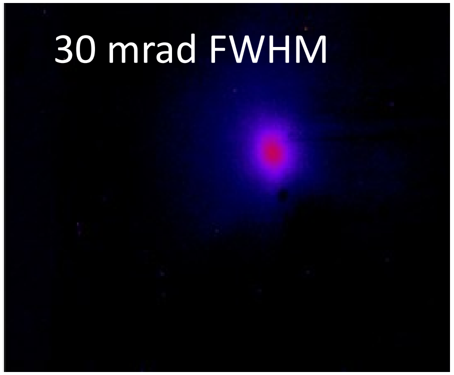
1. Laser energy @compressor output ≈ **6,38 J * 0.5 (transport efficiency)**
2. Laser energy in the focal spot ≈ **70%**
3. Laser duration ≈ **30 fs**
4. Laser transverse profile ≈ 9x9 pixel -> **18x18 um2**

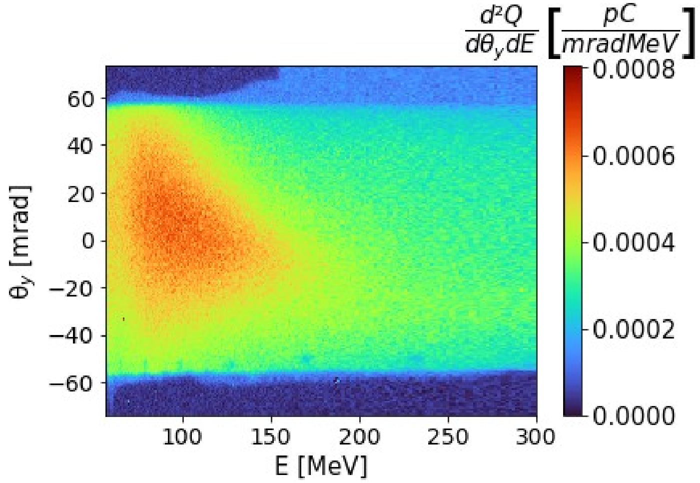


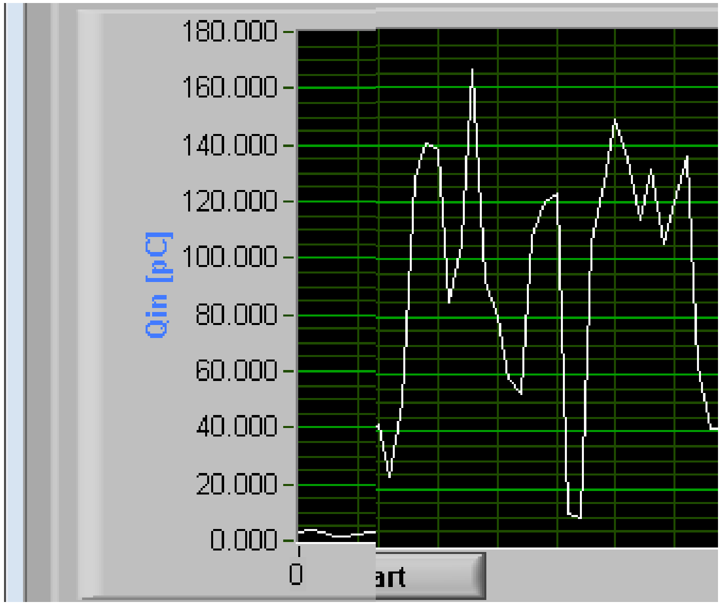


Accelerated e-beam parameters

1. e-beam divergence ≈ **30 mrad** and pointing stability ≈ **3 mrad**
2. e-beam charge @1.2m downstream the interaction point ≈ **150 pC**
3. e-beam maximum energy ≈ **250 MeV**

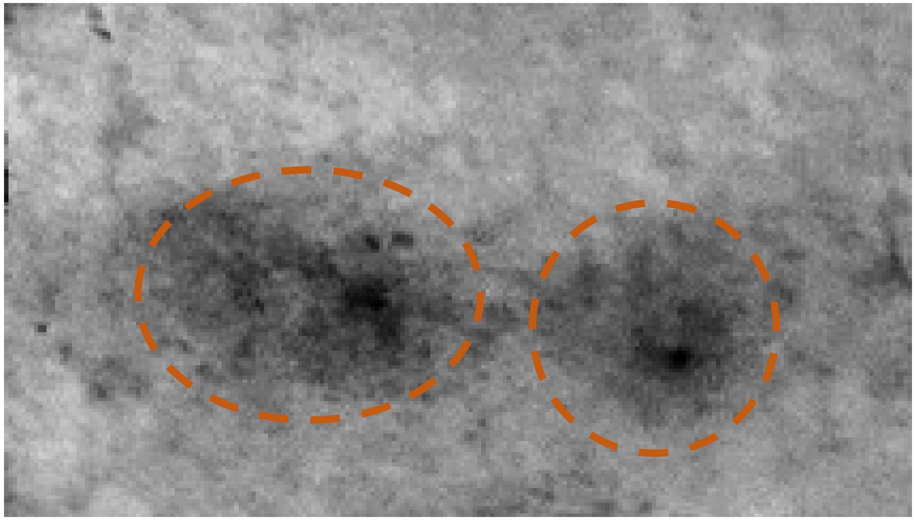


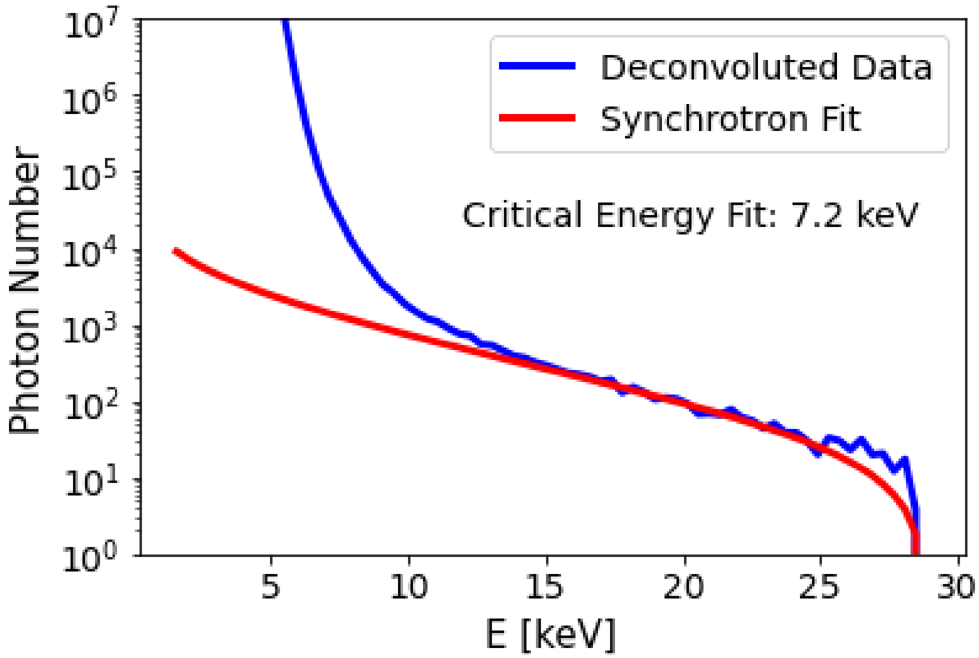




Betatron X-ray beam – preliminary results

1. X-ray beam profile – multi-shot acquisition
2. X-ray spectrum





Thanks!

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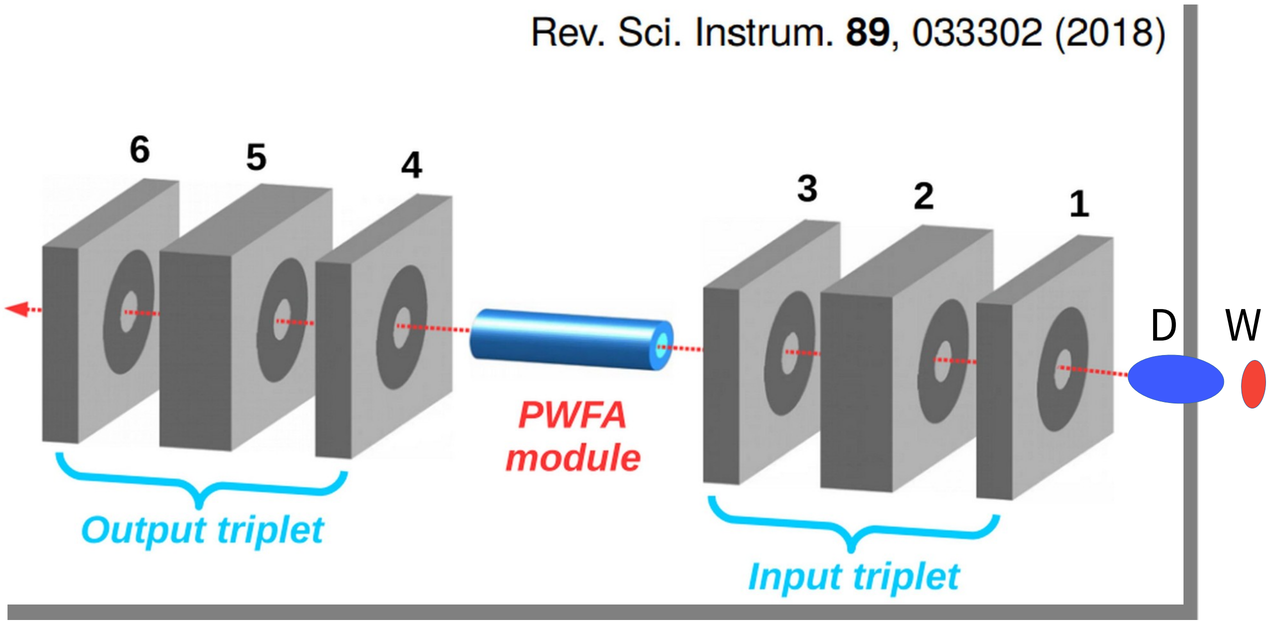
Acceleration and matching in a plasma



In a **PWFA** the beam must be transversely focused at the plasma entrance

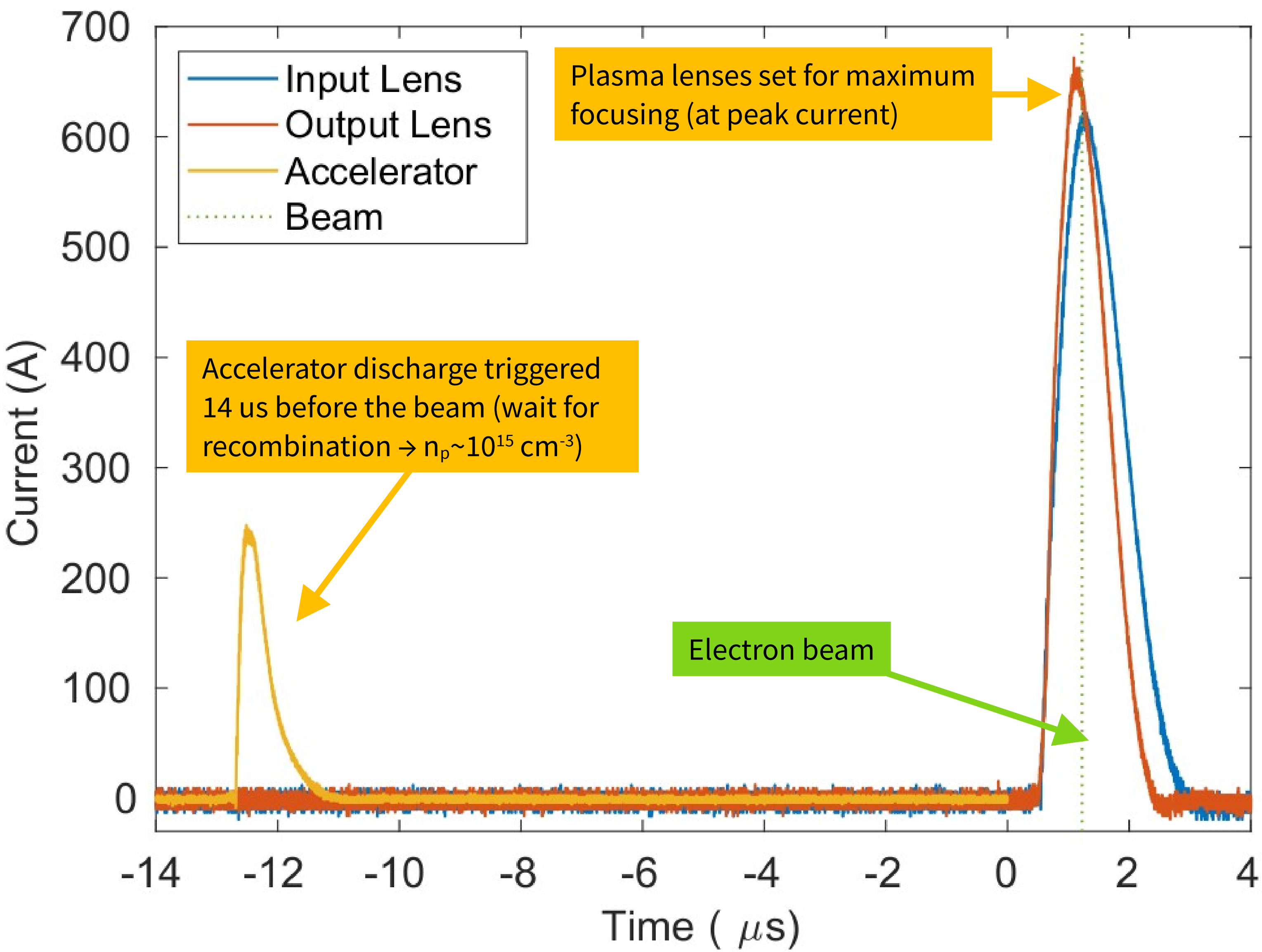
- *Driver beam charge density (together with plasma density) sets the accelerating gradient*
- *Witness beam must be transversely matched to avoid emittance spoiling*

$$\beta_{eq} = \sqrt{\frac{\gamma}{2\pi r_e n_p}}$$

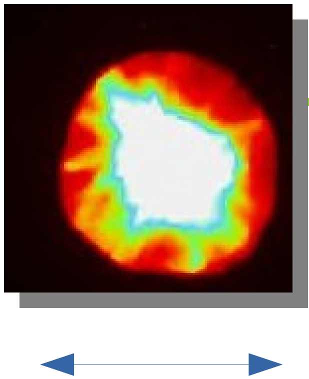
Barov, N., et al., Physical Review E 49.5 (1994): 4407.

The PWFA needs focusing optics upstream (matching) and downstream (capture)

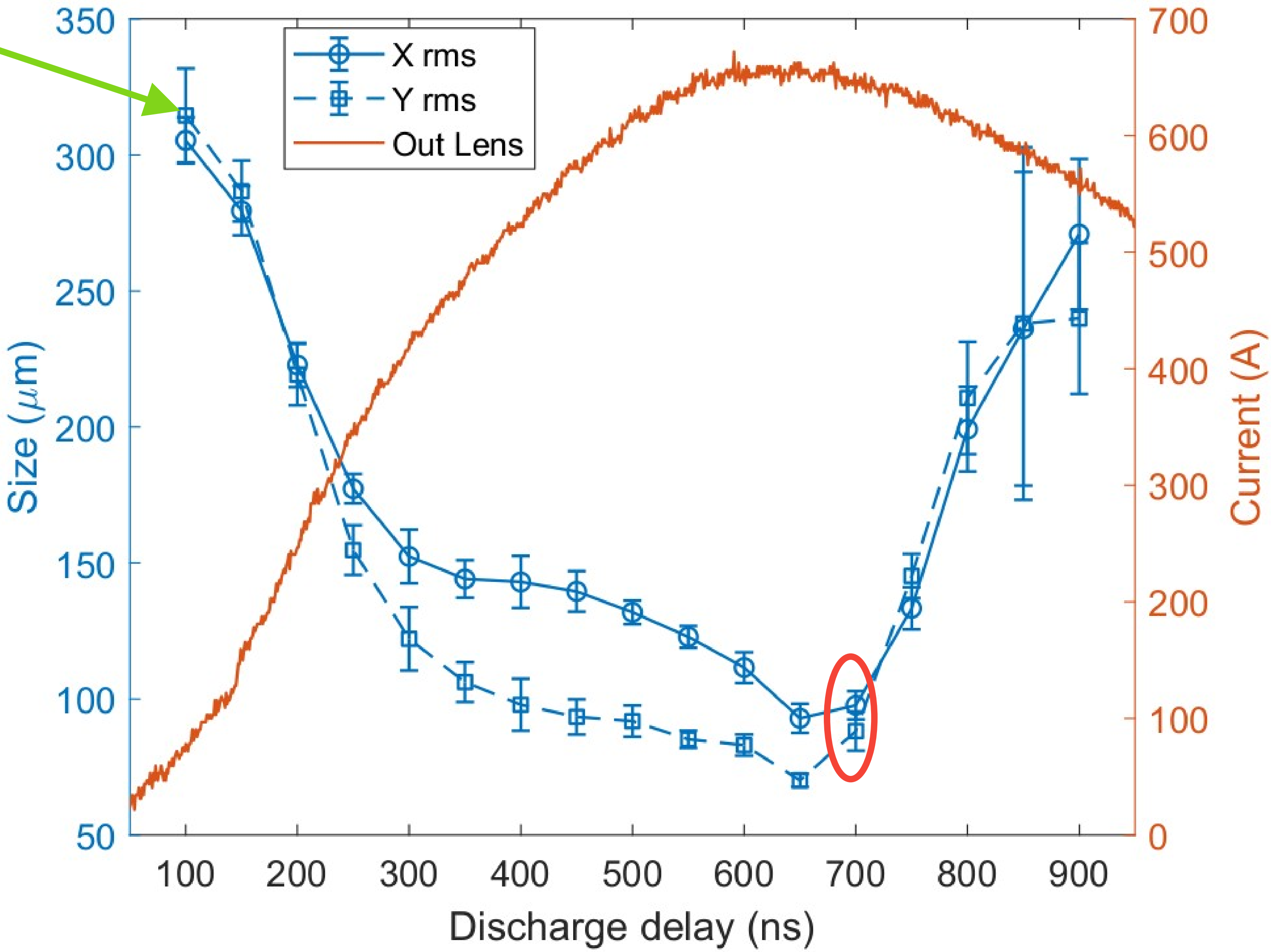
Discharges timing setup



APL scan

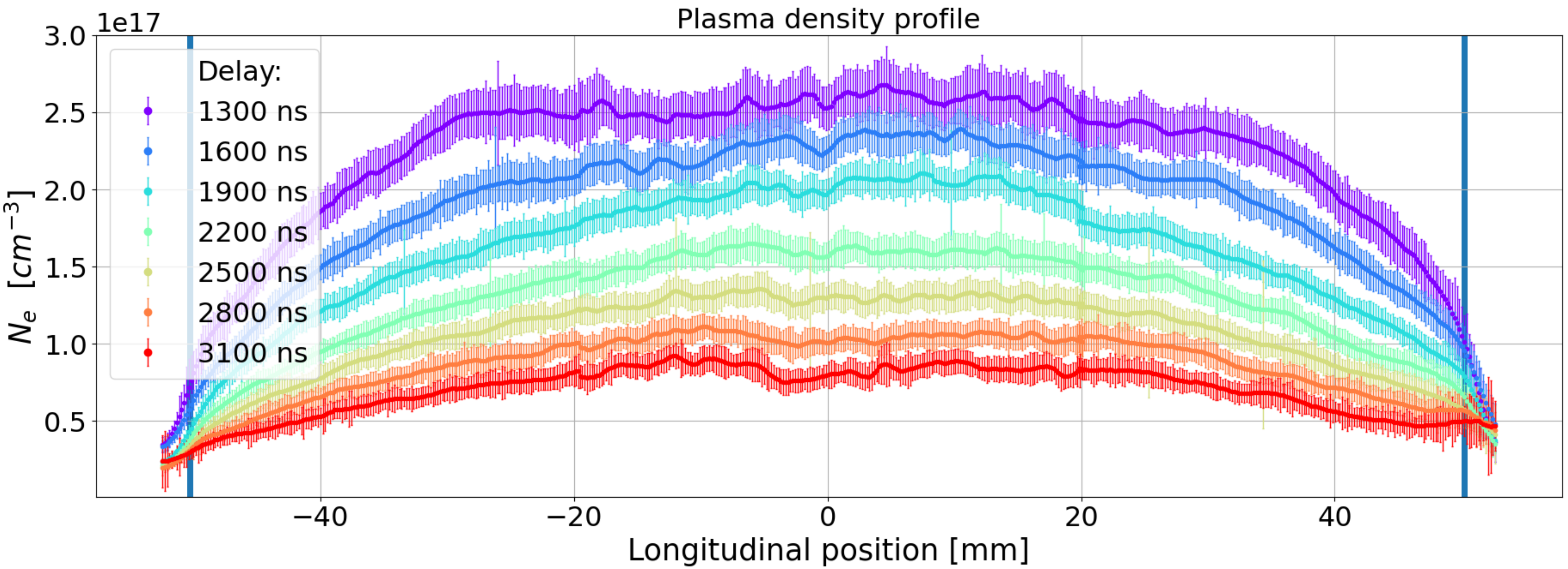


Scan obtained using only the APL2 (APL1 and ACC turned OFF)



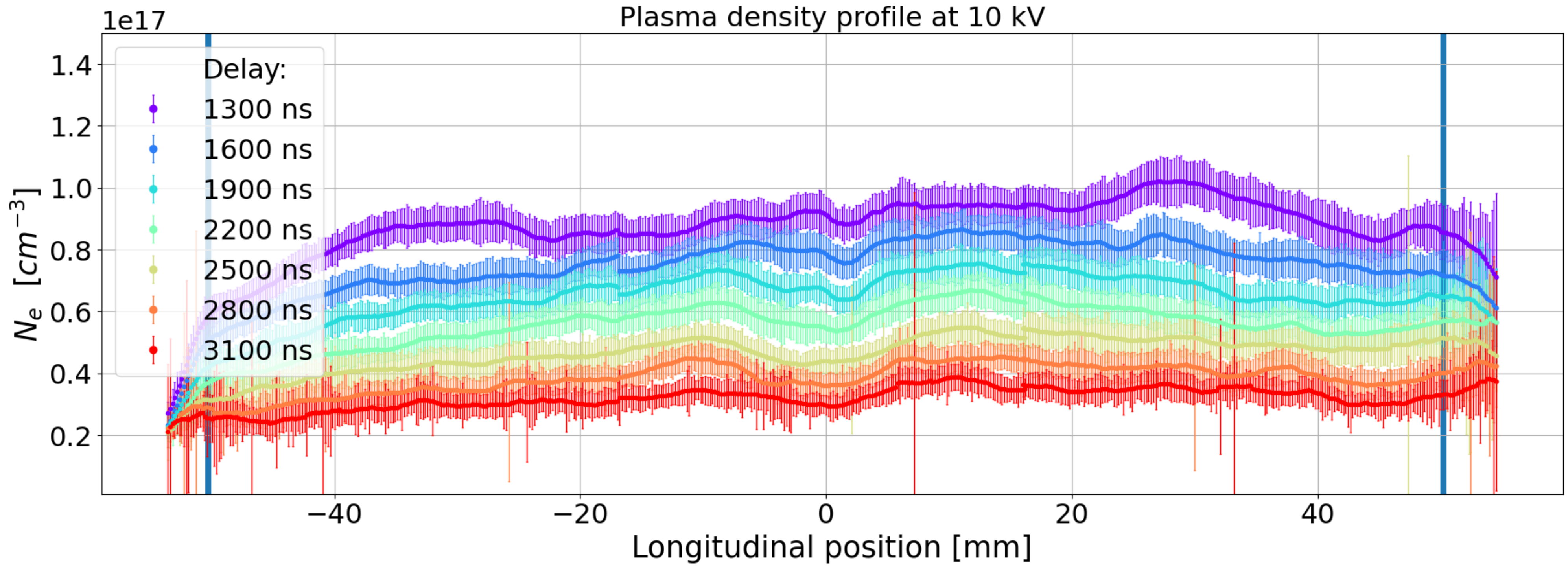
Plasma density measurements

Before test 10 kV – 730 A, 1 bar



After test

10 kV – 730 A, 1 bar



Degradation of the capillary (ablation) gave lower densities